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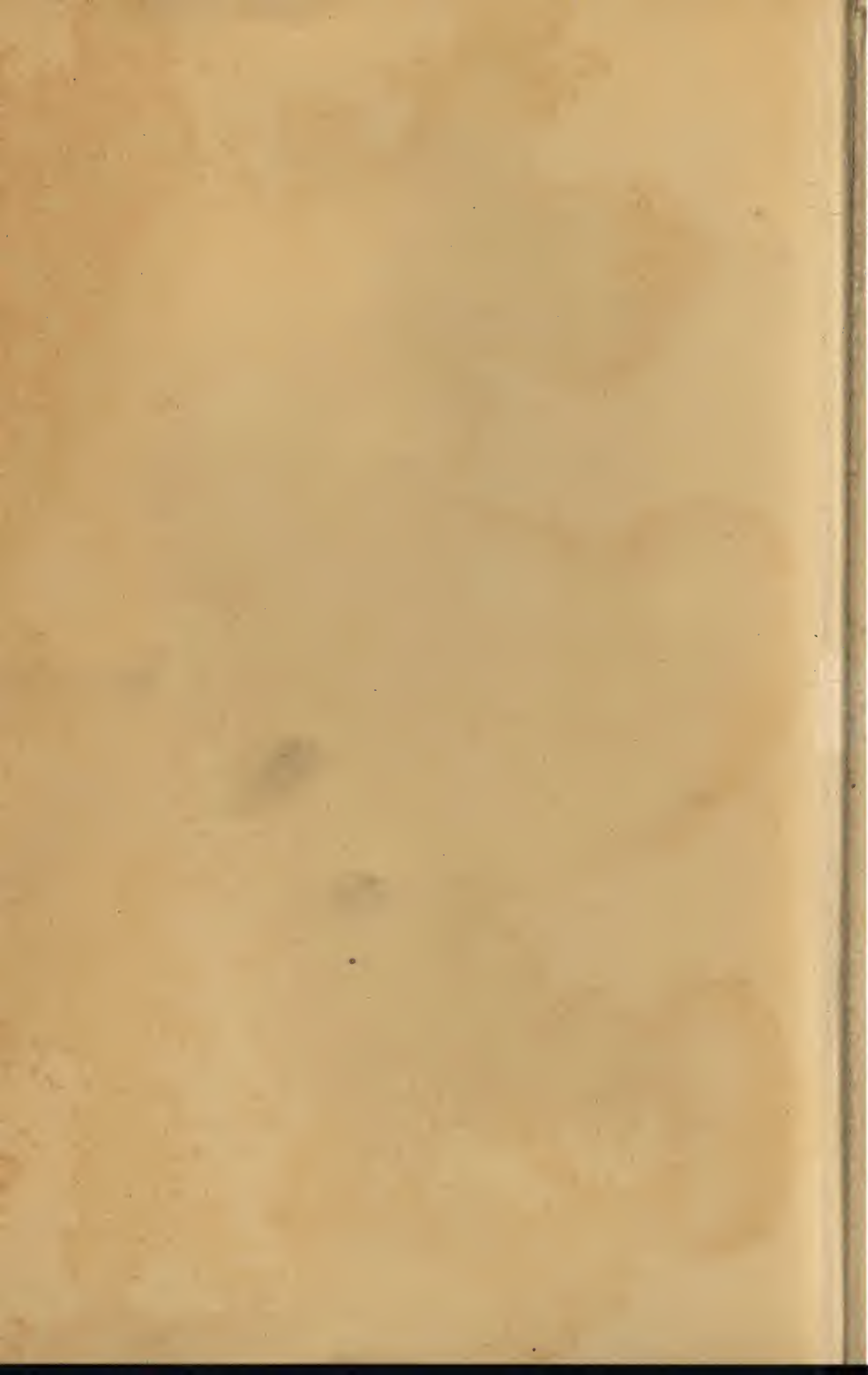
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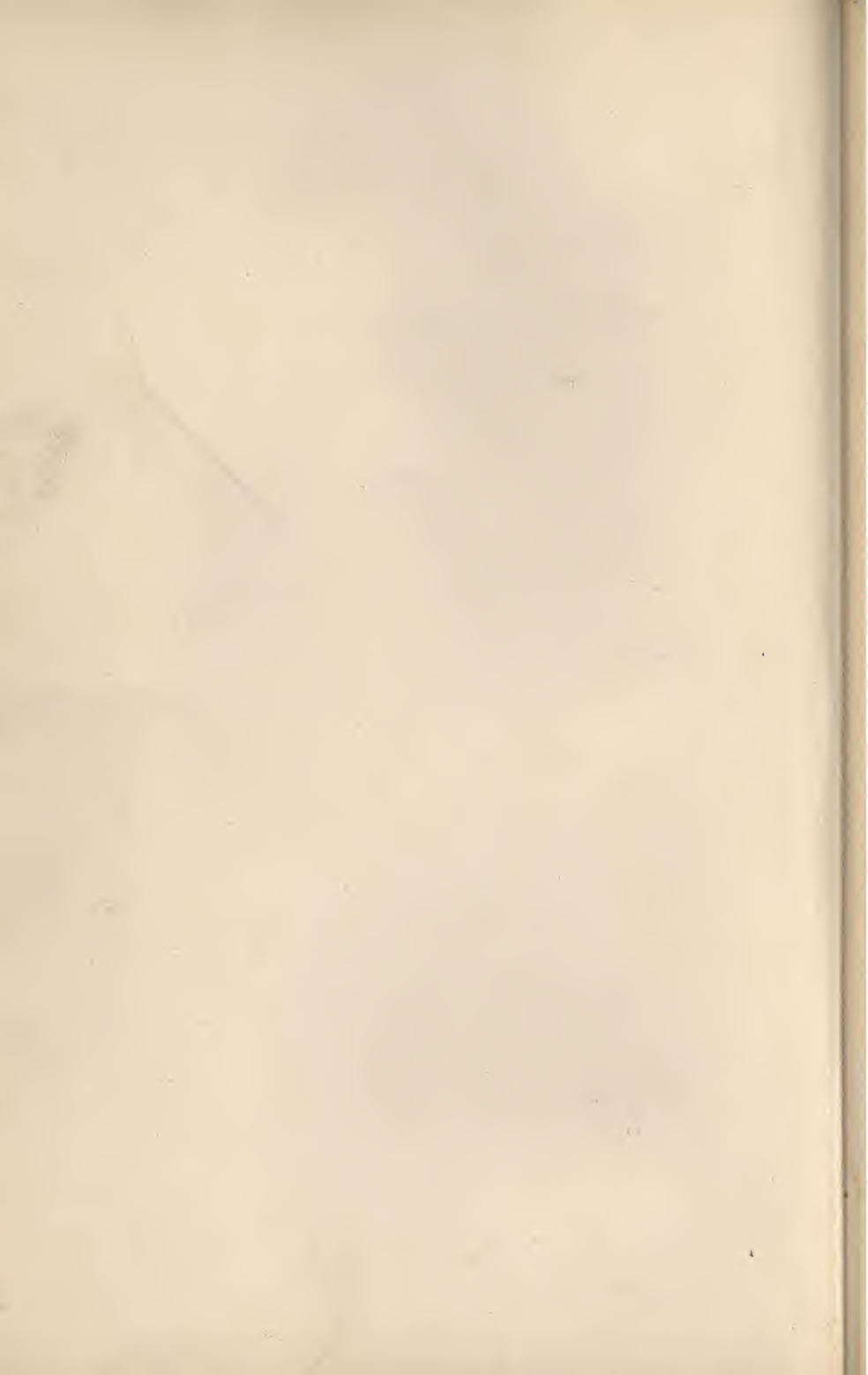
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Alan O'Bright



ELECTRIC METER
HISTORY AND PROGRESS





Electric Meter History and Progress

By
R. C. LANPHIER

SANGAMO ELECTRIC COMPANY
SPRINGFIELD, ILLINOIS

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FOREWORD

THE average man thinks of the great advances in the use and application of electricity in the past fifty years, principally in terms of great power houses with their huge turbines and generators. Or he thinks of the modern incandescent lamp, the electric motor, the manifold electrical household devices, or the radio. He does not realize that a great part of this development would have been impossible without accurate, simple and relatively cheap means of *measuring* electric energy and its factors.

MANY electrical engineers, indeed, fail to appreciate the great amount of scientific and technical skill, fully equalling that in any other important branch of electrical development, which has been devoted to the art of electrical measurement, and especially to "meters" in the now accepted sense of energy or quantity measuring devices.

WITH the thought that this brief history of the electric meter may give the reader a greater sense of the importance of meters to the electrical industry, this book is dedicated to the

*Meter Committees of
The Association of Edison Illuminating Companies
and
The National Electric Light Association*

R. C. LANPHIER

SPRINGFIELD, ILLINOIS
FEBRUARY, 1925

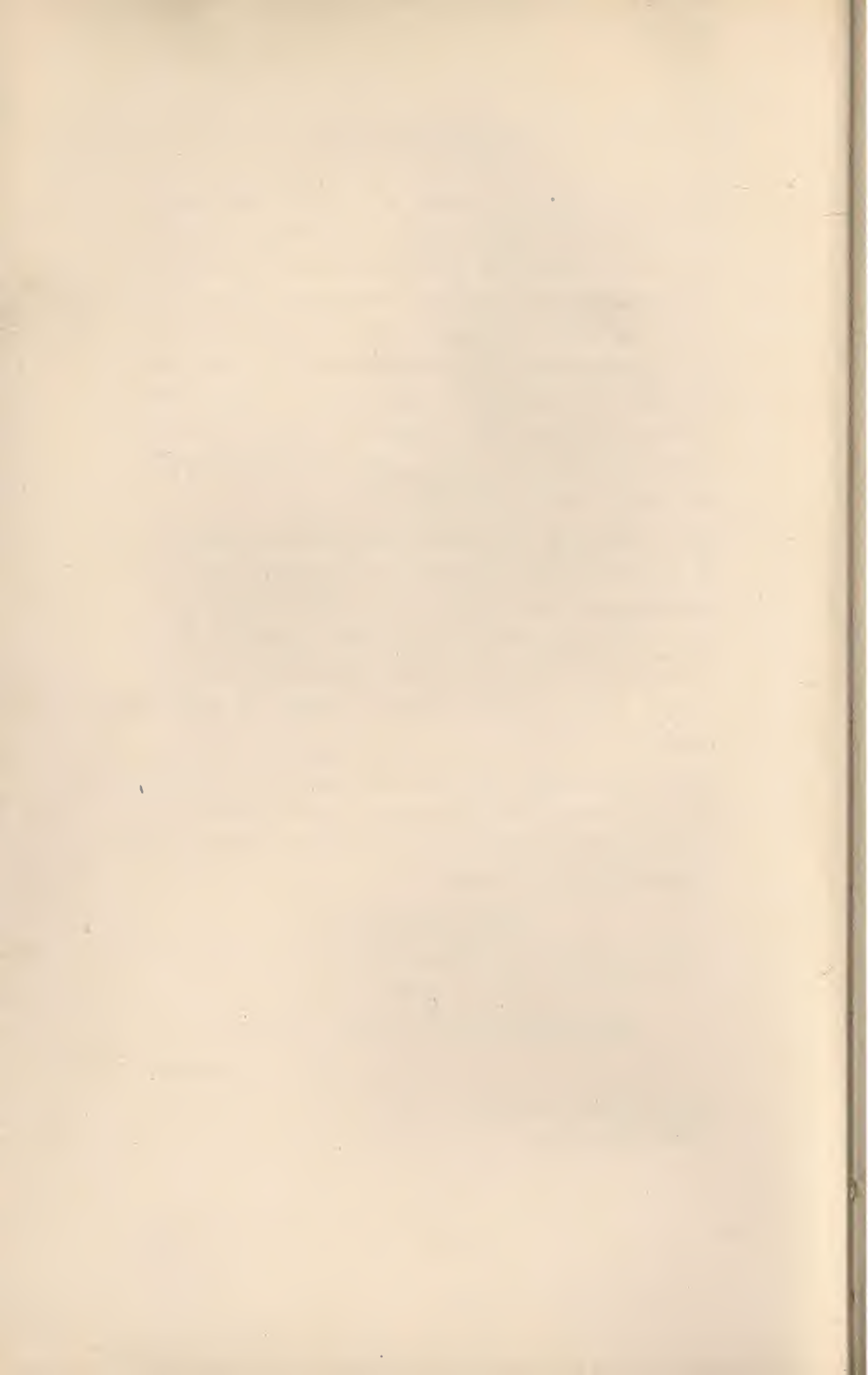
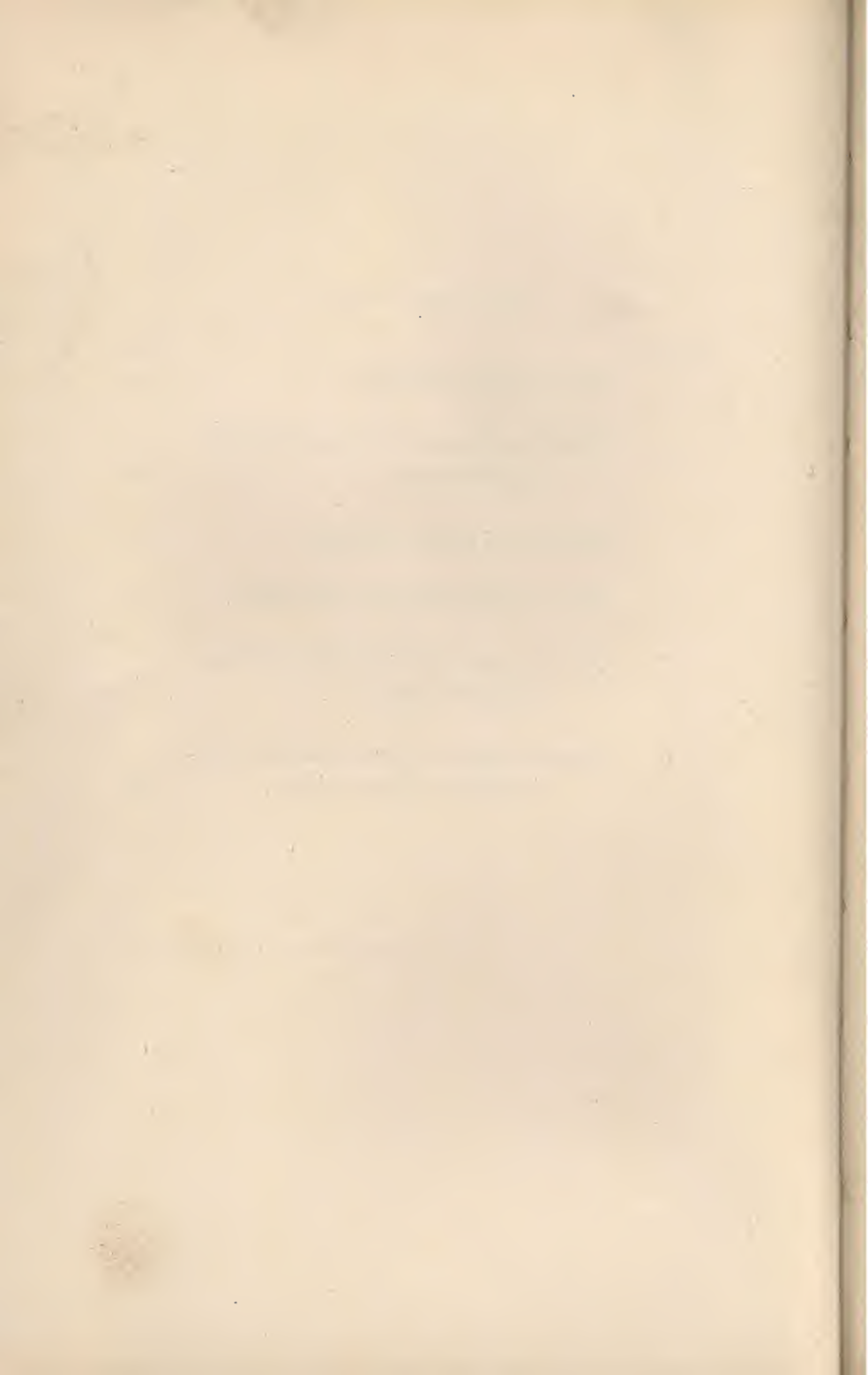


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Electric Meter History and Progress



CHAPTER ONE

Early Types of Meters

PRIOR to 1880 there was no central-station art as we think of it today. There were very few electric consumers and practically no lighting customers, so that the need for measurement of electric quantity or energy had hardly been felt at that time.

DIRECT-CURRENT METERS FIRST TO BE DEVELOPED

In the period from 1872 to 1879, a few attempts had been made by such men as Gardiner and Fuller to produce so-called electric meters. But these meters were really nothing more than intermittent-time devices recording the total time that a current existed in an electric circuit.

A patent for what was probably the first effective meter was taken out in England by John T. Sprague in 1878. This meter was an electrolytic meter in which two copper plates carried on spiral spring supports were made to reverse their polarity alternately when a given weight of metal had been deposited. The quantity of electricity passed was recorded by a train of wheels actuated on each reversal of current.

In 1879 or 1880 the genius of Edison was turned to

the development of the central station and parallel distribution to customers became an established and important fact. At this time the need for integrating meters was felt and Edison was the first to solve the problem that presented itself in a commercially satisfactory manner. At that period there was no thought of measuring electrical *energy*, that is, watt-hours. The early Edison meters, and others invented about the same time, were all *quantity* meters measuring coulombs or ampere-hours. Edison invented in the period from 1880 to 1882, two principal types of meters. One was a motor meter which did not appeal to him and which, while patented, was never manufactured commercially. The other was an electrolytic-deposit meter, well-known as the "Edison chemical meter", described in further detail on page 25.

About the same time Dr. Siemens and Prof. Ayrton in England realized the need of integrating meters. To

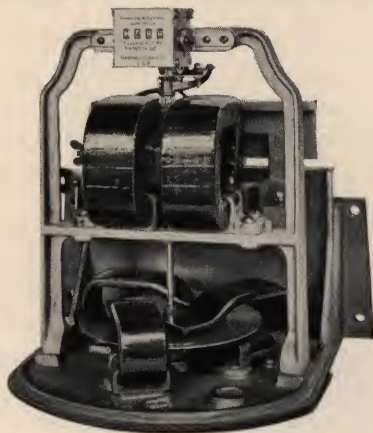


Fig. 1 Original Thomson commutator meter (Type TRW).

them is generally ascribed the credit of the first so-called "commutator-motor-type meter". Ayrton is generally credited with conceiving the idea of controlling the speed of a motor meter by utilizing the Foucault principle of a damping disk reacting with permanent magnets. The joint conceptions of Siemens and Ayrton were first reduced to a really successful commercial basis by Prof. Elihu Thomson who brought out the well-known Thomson meter at Lynn in 1888.

At the same time, Hookham and Ferranti in England independently developed and announced the first Faraday disk or mercury-motor-type *quantity* meters.

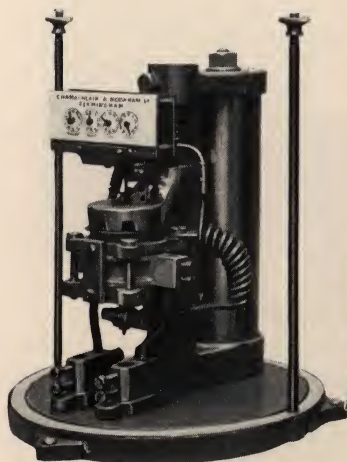


Fig. 2 Early Faraday disk mercury-motor meter, Chamberlain and Hookham, with cover removed.



Fig. 3 Early Faraday disk mercury-motor meter, Ferranti.

In these meters rotation of a copper disk partly or wholly submerged in mercury was produced by the

interaction of a suitable permanent magnet with an electric current through the disk.

EARLY TYPES OF ALTERNATING-CURRENT METERS

IN the meantime, about 1886, after the single-phase alternating-current system of distribution became of commercial importance, several engineers in this country and abroad attacked the problem of a type of meter adapted only to alternating current. Prof. Ferraris first enunciated the principle of the rotating field in an address before his students at Turin in 1886 or 1887, his discovery being made in 1885. It is interesting to note that his conception of the rotating field was primarily for the purpose of producing an electric meter, or as then usually termed, "recording wattmeter".



Fig. 4 Ferraris model presented to John W. Lieb in 1922 by the Associazione Elettrotecnica Italiana. It is a true reproduction of the original model made by Ferraris in 1885 and presented to the Accademia della Scienze di Torino, March 18, 1888.

His announcement was immediately followed by the appearance of the first alternating-current meter, made by Borel and Paccaud in France. But the first really great work in the alternating-current meter art was that of Oliver B. Shallenberger, at that time assistant to Mr. William Stanley who was then Chief Electrical Engineer of the Westinghouse company. Shallenberger was without question one of the greatest engineers and inventors the electrical art has

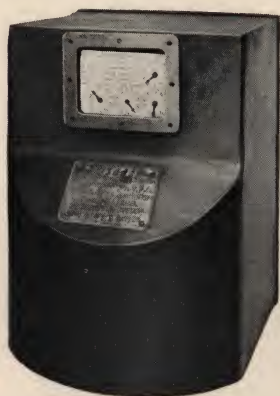


Fig. 5 The original Shallenberger induction amperehour meter.

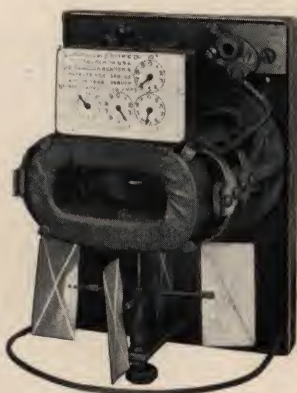


Fig. 6 The original Shallenberger induction amperehour meter with cover removed.

known. His invention of the first alternating-current amperehour meter, while partly from accidental observation of a peculiar phenomenon one day while working in his laboratory, was of far-reaching importance.

Shallenberger's original meter, produced by the Westinghouse company in 1888, was purely an amperehour meter. It consisted of a pair of coils in series

with the line, having within them two short-circuited copper coils set at an angle to the main coils and finally, within these secondary coils, a small disk rotor. Rotation of this disk was produced by the interaction of the out-of-phase fields set up by the main and secondary coils, the speed of rotation thus being proportional to the square of the current. This necessitated a retarding or damping force proportional to the square of the speed. Mr. Shallenberger solved this problem in a most ingenious manner by a system of air-damping vanes carried on the meter shaft. The Shallenberger



Fig. 7 Duncan lamp-hour meter.

meter and others such as the Duncan lamphour meter developed later, but based on the same principle, continued to be the most important meters in the alternating-current art for nearly ten years, that is until the watthour meter was produced.

While these meters destined to survive were being developed, many others were conceived, many were patented, and nearly all passed into oblivion. A few,

however, embodied real inventive genius and deserve mention,—among them, Prof. Thomson's "Oscillating-tube" or "rocking-beam" meter, which he built shortly before his famous commutator meter. In this meter a horizontal glass tube with a bulb arranged at each end was centrally mounted on an axis about which it was free to oscillate, its movements being communicated to a train of gears through a suitable ratchet arrangement. The tube and bulbs were partly

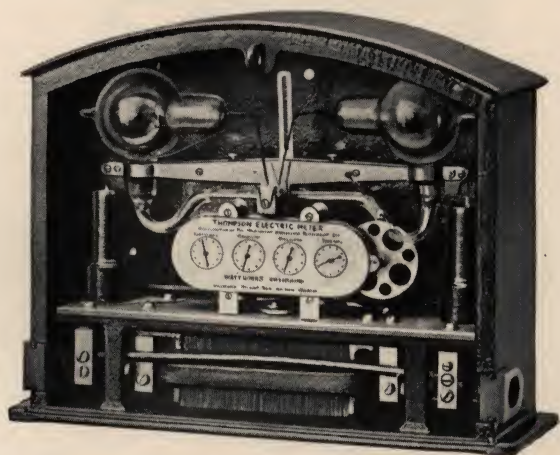


Fig. 8 Thomson Beam Meter, old model with cover removed, as exhibited at Louisiana Purchase Exposition in 1904.

filled with liquid and each bulb was surrounded by a heating coil so arranged that oscillation of the tube would cut the coils alternately in and out of the circuit. Oscillation of the tube was produced by the coils heating first the one and then the other bulb, thereby causing the liquid to flow alternately out of one bulb and into the other. The rate of oscillation was propor-

tional to the current and since the ratchet arrangement counted the oscillations the total quantity of electricity could be recorded on the dial. This meter was subject to many irregularities and did not survive.

Another interesting meter was the so-called "windmill" meter of Prof. George Forbes, the famous Scotch



Fig. 9 Professor Forbes' windmill meter.

engineer whose advice was so valuable in connection with the early hydroelectric developments at Niagara Falls. His invention was probably the first important attempt to meter alternating current. The Forbes meter, which was equally suitable for direct current, consisted of a very light spiral vane carried in a tube above a heating coil and attached to a very fine jeweled gear train. The heat from the coil was propor-

tional to the square of the current and the rotation of the spiral-vane rotor, retarded under a square law, was proportional to the quantity of energy passed. This meter received the medal of the Franklin Institute in 1888 as a recognition of the inventive genius displayed, but was never commercially manufactured.

Many other peculiar and freak types of meters were produced in this early period and even so late as 1902, but in recent years all such types have disappeared.

TYPES OF COMMUTATOR-MOTOR METERS

IN the early days of the art—in fact until about 1900—commutator-motor-type meters, having no iron in the armature or series coils, were widely used on alternating-current circuits, especially where measurement of energy rather than quantity was desired. But since that time this type of meter has had almost its entire application on direct-current circuits. The earliest successful type of motor meter was essentially a small shunt motor, having an armature wound with a number of sections of very fine wire and equipped with a suitable commutator and brushes, connected in series with a high resistance across the circuit to be measured. The main or series coils of commutator-motor type meters are connected in the line so as to carry the entire load current. Motion is transferred from the shaft to a train of gears or register. Speed control is effected by a copper or aluminum disk passing through the gaps of permanent magnets. Light-load compensation or correction for initial friction is obtained in various ways, but all involving the reaction of a coil in the voltage circuit with the armature.

This "starting coil", as it is called, has been arranged in some meters of this type to move in and out with respect to the armature; in others to tilt, and in others to swing. In still others the coil has been fixed and its effect varied by a small rheostat cutting in more or less of its turns. This general type of meter has been built in many forms and with many modifications in this country and abroad since 1888. It is still the most widely used type of direct-current watthour meter.

Confusion existed for a great many years in the use of the incorrect term, "recording wattmeter", for



Fig. 10 General Electric (Thomson) modern commutator meter.

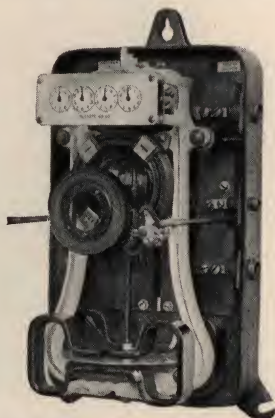


Fig. 11 General Electric modern commutator meter with cover removed.

what is now correctly called "watthour meter". Obviously a recording wattmeter is a graphic instrument recording power values on a chart. Recognizing the inaccuracy of this term, American manufacturers about twenty years ago adopted the better expression "integrating wattmeter". But a few years later, at the

suggestion of the U. S. Bureau of Standards, this term was dropped and all American manufacturers and many foreign ones have since employed the correct term "watthour meter", or "kilowatt-hour meter" for all types of alternating-current and direct-current energy meters. Similarly, the term "amperehour meter" is correctly employed for direct-current quantity meters, there having been no alternating-current quan-

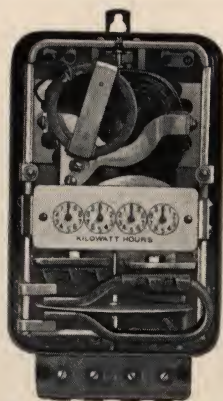


Fig. 12 Duncan modern commutator meter.

tity meters in use for many years. English manufacturers have long employed the general term, "electricity meter" for both quantity and energy meters.

Another type of direct-current meter that has been widely used in Europe for more than twenty years, although to no extent in this country, is the commutator-type amperehour meter. It consists essentially of an armature connected across a shunt in the line and reacting with the field of a permanent magnet. The driving and retarding forces are thus directly proportional to the current and give an indication on

the register of quantity, that is, amperehours. This meter has the advantage from the European standpoint of being considerably cheaper and smaller than a commutator-type watthour meter. It is also considered especially advantageous because, having no voltage coil, it is free from the rather heavy continuous losses found in nearly all commutator-type watthour meters. Many users feel that the lower accuracy of the direct-current commutator amperehour meter on light load as compared with the watthour meter is



Fig. 13 Sangamo commutator-type amperehour meter.

offset by the elimination of voltage-circuit losses. It is interesting to note in this connection that a modern direct-current watthour meter having a voltage-circuit loss of say four watts at 110 volts, represents a loss in 24 hours of 96 watt-hours, or nearly three kilowatt-hours per month. As many small consumers have a consumption of only 15 to 20 kilowatt-hours per month, it can readily be seen that voltage-circuit

losses in direct-current meters are a matter of great importance.

THE DEVELOPMENT OF THE MERCURY-MOTOR METER

THE other most important type of direct-current meter is the mercury-motor watt-hour or ampere-hour meter. From the early meters of Hookham and Ferranti several manufacturers, including the companies founded by these men in England, have developed excellent types of mercury-motor meters, embodying many features not found in other direct-current meters. Among these features are immunity to stray fields and to heavy vibration and adaptability to use with shunts for heavy loads. All of these features are important from the standpoint of first cost, ease of installation, and calibration. The mercury-



Fig. 14 Modern Ferranti Meter.
An English amperehour meter.

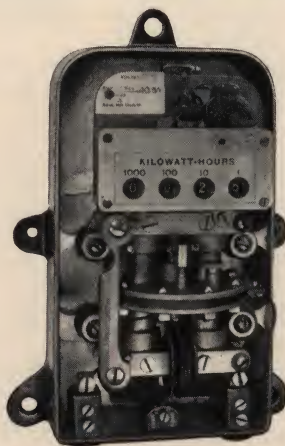


Fig. 15 Modern Ferranti Meter
with cover removed.

motor meter is probably more widely employed today on heavy loads than any other type of direct-current meter.

The mercury-motor-type amperehour meter is almost universally employed in Great Britain on consu-

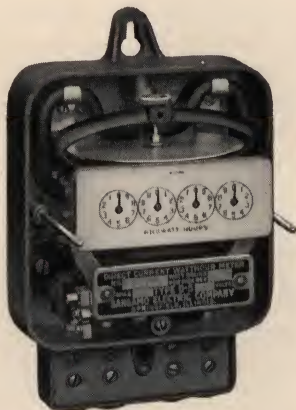


Fig. 16 Sangamo mercury-type watthour meter as manufactured since 1910, main and terminal-box covers removed.

mers circuits where nearly three-fourths of the consumers are still supplied with direct-current energy. Direct-current watthour meters have never found the favor in Great Britain that they have in this country.

CLOCK-WORK TYPES OF METERS

ANOTHER interesting type of direct-current meter and probably the most accurate that has ever been produced, is the Aron differential clock type. This was invented by Dr. Aron in Germany in the late eighties and even to this day it has no equal

where the utmost sustained accuracy in measurement of direct-current energy is desired. It is, however, far too complicated and expensive for ordinary use and now has small sale. In this meter there is a clock-work having two pendulums, each of which carries a coil



Fig. 17 Aron differential clock-type meter.

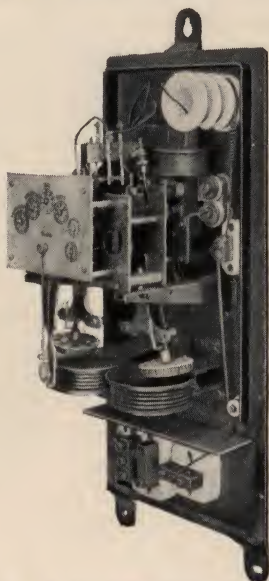


Fig. 18 Aron differential clock-type meter with cover removed.

energized by the electromotive force of the circuit. These pendulums swing above two coils in series with the line. So long as no electricity passes through the current coils, both pendulums swing at the same rate. Under these conditions the differential gears driving the meter register from the electrically wound clock-work remain stationary. However, the moment the smallest amount of electricity passes through the

meter, the periods of oscillation of the pendulums differ in proportion to the energy passing. The differential transmits motion to the register exactly in proportion to the difference in the pendulum rates and energy units are recorded. The curve of the meter remains practically straight up to the highest load, thus giving a most interesting type of instrument.

A number of other so-called "clock-work" meters have been devised, but space does not permit their mention.

OSCILLATING-TYPE METERS

ANOTHER type, used considerably in the past but to very small extent now, is the oscillating direct-current meter in which an armature moves through an arc under the influence of series fields, instead of rotating. At each end of the armature's travel connections are automatically reversed so that the armature continues to move back and forth from one end of the arc to the other. The oscillations are counted through a suitable ratchet arrangement and recorded as watthours by the gear train. This type of meter has little to commend it.

ELECTROLYTIC METERS

A FINAL and very important general class of direct-current quantity meters, is the electrolytic type, of which there are three general forms. The first are those meters which liberate gas from acid solution. The measure of the quantity of electricity passed is the displacement of liquid by the gas in tubes suitably arranged with respect to a scale reading in ampere-hours.

The second, and probably most interesting type, is

the metal-deposit type, of which the original Edison chemical meter is the best example. In this meter there were two zinc plates in a cell filled with electrolyte. The cell was connected across a suitable shunt in

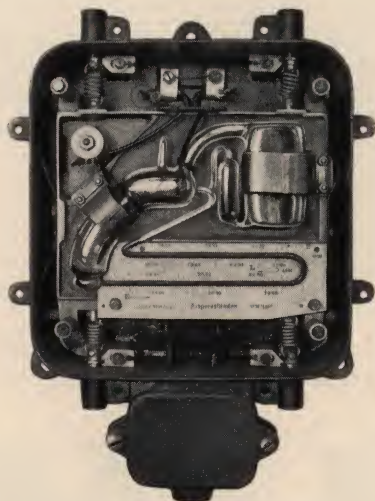


Fig. 19 German gas-type amperehour meter recovered from German submarine, cover removed. Courtesy of U. S. Navy.

the load circuit. With passage of electricity, zinc was transferred from the anode to the cathode. By weighing the cathode plate at the beginning and end of a period, its increase in weight, and thus the quantity of electricity which had passed, was readily ascertained. This type of meter was generally used by the large Edison companies of this country and abroad on their direct-current lighting circuits from the early eighties until about 1900. It was purely a quantity meter, but considering the state of the art in those

days, it was admirable in its performance and results. To prevent the electrolyte from freezing in cold



Fig. 20 Edison chemical meter with cover opened.

weather and thus putting the meter out of commission, a lamp was placed inside the meter.



Fig. 21 Reason electrolytic meter.

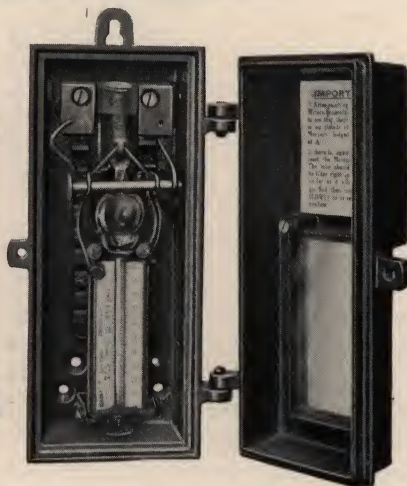


Fig. 22 Reason electrolytic meter with cover opened.

The third type of electrolytic meter and the one generally used today, is the mercury-deposit type. The best example of this type is the Reason meter of England and the Stia of Germany, which is based on the Reason patents. In this meter, mercury is precipitated out of chemical solution by the passage of electricity and is carried over into a tube placed before a graduated scale. This scale is so calibrated that the height of the mercury gives a direct reading in ampere-hours. All electrolytic meters, as compared with other types of direct-current meters, have the advantage of recording every unit of electricity that has passed, no matter how small in value compared with the capacity of the meter.

CHAPTER TWO

The Development of the Induction-Type Meter

FROM the beginning of alternating-current distribution until the early 90's, when the polyphase system became a commercial success, there was little need for an alternating-current watthour meter. The Shallenberger amperehour meter already described, or similar meters, were principally used on the single-phase systems. It was obviously possible to use a commutator-type watthour meter on alternating-current circuits with reasonably satisfactory results. Meters of this type were used to a considerable extent for measuring energy in single-phase systems until the induction-type watthour meter was developed. Following the Frankfort-Lauffen polyphase transmission in 1894 and the introduction of polyphase motors, the need of a meter adapted to measure correctly inductive loads was recognized. Many inventors of international reputation turned their minds to this problem which was solved by Shallenberger.

An interesting story is told by Mr. Charles A. Terry, now Vice-President of the Westinghouse Company, and at that time its patent counsel, about this important invention. Mr. Terry, who was Mr. Shallenberger's intimate friend, was with him at Atlantic City early in 1895. One day while sitting on the sand, Mr. Shallenberger spoke of the importance of finding

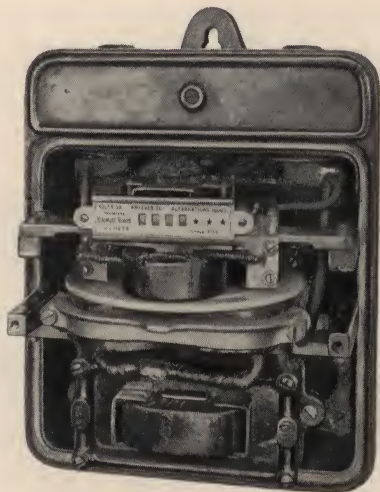


Fig. 23 Shallenberger induction watt-hour meter of 1896.

some means of making a small single-phase motor, suitable for use as a meter, and with such relations between its current and voltage elements that the meter would measure correctly at any power-factor of load. He then traced on the sand the vector diagram showing the relations of impressed electromotive force and the phase angle of the voltage circuit of meters made up to that time. He then added the vector of a secondary circuit reacting with the main flux of the voltage-coil circuit so as to give a resultant or effective flux in quadrature relation with the impressed electromotive force. A patent was immediately applied for on this invention, followed by other patents embodying various means of carrying out this principle in several types of meters. These patents were soon allowed and were most important in the art.

The need of an induction-type watthour meter, accurate on low power-factor, was particularly emphasized at this time by the building of the Niagara Falls plant. It was here that the first Shallenberger-

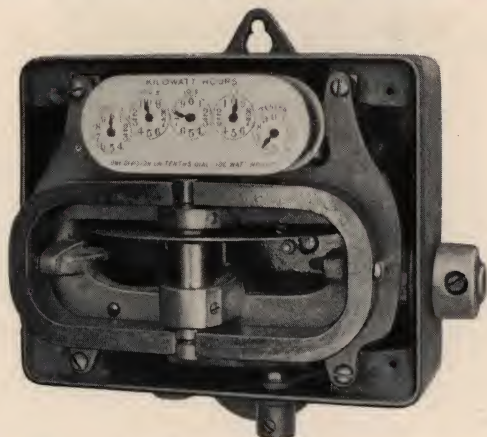


Fig. 24 Stanley watthour meter with cover removed.

Westinghouse watthour meters, embodying quadrature of the shunt field, were used. All modern induction meters throughout the world embody this feature in some way, for otherwise they would be useless except on purely non-inductive loads.

Other pioneers in the induction-meter art, aside from a number abroad not of particular interest to us, were Scheefer, Duncan, Gutmann, and Stanley. The induction meters of these and other inventors were brought out in this country during the years 1894 to 1900. Of these meters the most interesting was the Stanley which embodied the then famous magnetic flotation for the moving system. The heavy permanent magnets which served as the control mag-

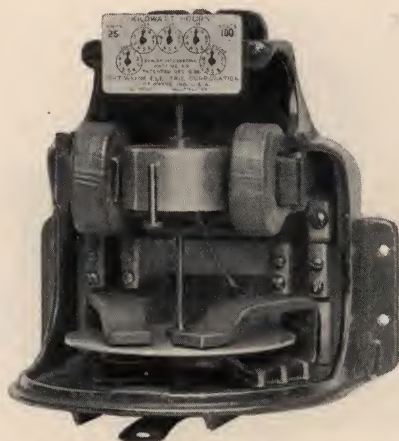


Fig. 25 Duncan Fort Wayne alternating-current watthour meter of 1899.

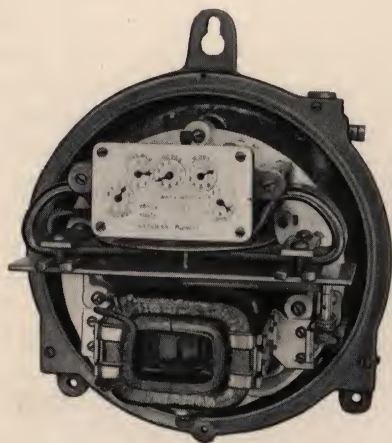


Fig. 26 Scheefer alternating-current watthour meter of 1898.



Fig. 27 Gutmann watt-hour meter of 1899 with cover removed showing cylindrical armature.

nets for the moving system were so arranged in this meter that the aluminum disk, suspended on a steel shaft guided by a piano wire, literally *floated* in the gap space of the driving and retarding structures, and therefore had no bearings in the ordinary sense. This construction, while it had many advantages, was expensive and after a time gave trouble due to several causes. As a result, it has not survived in modern meters, as the reduction in weight of moving systems and improvements in lower bearings have made such complication unnecessary.

INDUCTION-METER ART NOW STANDARDIZED

BY the year 1900 the alternating-current system of distribution, both polyphase and single-phase, was becoming more popular throughout the world

than direct-current systems, which at that time, in the United States, became confined principally to a few large cities and to traction work. The demand for alternating-current meters was therefore greatly stimulated and a number of manufacturers were engaged in making the several types of meters mentioned. However, from 1900 to 1904, patent litigation was carried on under the famous Tesla split-phase patents Nos. 511,559 and 511,560, which were owned by the Westinghouse Company with license rights to the General Electric Company. These patents, after long, bitter and expensive litigation were eventually sustained as covering practically all types of single-phase motors, and without question, motor elements of induction meters. From the early part of 1904 until the expiration of these Tesla patents in December, 1910, induction meters were made only by the owners and licensees of these patents. Naturally this resulted in the absence of incentive to other manufacturers and inventors in this art during the period mentioned with the result that further important developments in the induction-meter art were largely delayed until after 1910. The alternating-current meter art is now thoroughly standardized throughout the world, and while there are many types, both of single-phase and polyphase meters, all operate on the same principle, —that is, of the Ferraris or Tesla rotating field. The various meters differ widely, however, in details of design, such as weight and form of moving system, upper and lower bearings, arrangement of retarding magnets, driving structures and registers. They also differ in power-factor, light-load and full-load adjustments, in losses and in torque.

As a class, the four well known makes of induction

meters in the United States are superior to most foreign meters. The latter are frequently built as cheaply and light as possible, while American meters are staunchly constructed, well built throughout and, if given even the most reasonable attention, are dependable for many years. The fact that the sale of



Fig. 28 The Siemens-Schuckert meter—a foreign induction watt-hour meter.

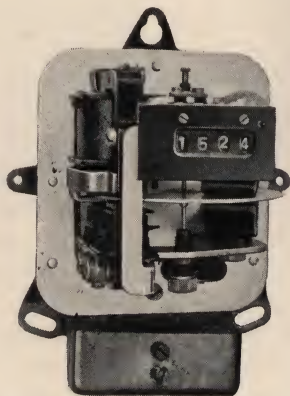


Fig. 29 The Siemens-Schuckert meter with cover removed.

alternating-current meters in the United States is greater than the combined sale of such meters in all the other countries of the world, perhaps accounts for the standard to which American meters have been brought and maintained. It is estimated that the present requirements of meters in the United States are over 2,000,000 annually, of which only a small fraction is direct-current meters.

CHAPTER THREE

Features of Meter Design

THE inventive ingenuity and mechanical skill shown in many features of meter design attest the attention given this phase of electrical development by engineers during the past thirty years. Some of the more important of these elements of motor-meter design will now be briefly discussed.

METER-BEARING DESIGN

The upper bearing in practically all induction and commutator-type meters consists of either a steel pivot on the shaft of the moving system guided in a metallic bearing ring, or else of a stationary pivot with the bearing ring on the shaft of the moving system. Various expedients are used to avoid chattering of this bearing in alternating-current meters. The usual method is to give a certain degree of flexibility to the pivot. The lower bearing of all motor meters, except the mercury type, consists of a cup jewel, (except in the case of one well-known make of meter) and the lower end of the moving system is a highly polished, rounded steel pivot of considerably less radius than that of the cup jewel. In the exception referred to, the lower end of the shaft of the moving system carries a cup jewel between which and the jewel in the lower bearing, is a small steel ball, which thus presents changing points of contact against the

two jewels. This bearing was invented in the late nineties by Mr. McCoy, formerly of the United Electric Light Company of New York City.

The problem of the jewel in modern induction meters, having light moving elements, is by no means so serious as with meters having a comparatively heavy moving system such as the usual commutator-motor type of meter. For induction meters cup jewels either of natural Ceylon or Montana sapphire, or synthetic sapphire, are almost universally used. For large-capacity commutator meters, diamond cups have been used in recent years with great success. The hardness of a diamond is so great in comparison with sapphire (corundum) or any other known material, that it is difficult to describe the difference. Suffice it to say that the diamond cup is unnecessary for ordinary induction meters and far too expensive for general use.

A great deal of study has been put on the problem of

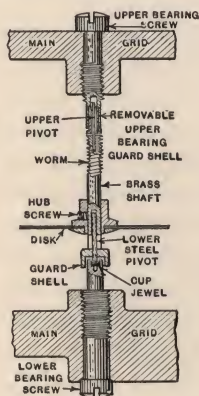


Fig. 30 Bearing system of Sangamo Type H watt-hour meters showing pivot and cup jewel.

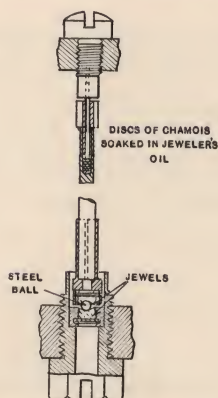


Fig. 31 Bearing system used in Westinghouse meters showing ball and cup jewels.

jewels and jewel-bearings for meters. As a result, methods of testing the stone to determine its true corundum quality and methods of grinding, polishing, and inspecting, have been brought to a high state of perfection.

With the development of very satisfactory synthetic sapphire, this material has been widely adopted for jewel bearings of meters, watches, and other instruments. The reduction of the weight of the moving system in commutator motor meters from eight or nine ounces in the earliest meters, to two or three ounces in the present types, is interesting and important. It has greatly improved the life of the bearings and has resulted in a higher maintained light-load accuracy. In induction meters the weight of the moving system is very low, varying from nine grams in some of the smallest meters made, to a maximum of twenty grams in other types. The average weight of the moving system in American meters is 13 to 15 grams. This weight means a tremendous theoretical pressure per

unit area on the jewel because of the extremely small area of contact. Yet this theoretical pressure, running to many tons, does not result in any such wear as might be supposed. In some meters having heavy moving systems, the jewel is supported on a spring to protect the pivot and jewel against the effect of severe jars or shocks in transportation and handling.

THRUST IN MERCURY METER IS LIGHT

THE mercury-motor meter has a moving system entirely different from that of commutator or induction meters. The effective thrust of the moving system is small and may be either upward or downward. Its value is the difference between the buoyancy of the armature immersed in mercury and the weight of the retarding disk, or counterweight, and of all other parts of the rotating element situated above the mercury chamber.

In the English mercury-type amperehour meters the moving system is supported on a cup jewel at the bottom, with almost a needle pivot on the lower end of the shaft and a very fine pivot in a guide ring at the top. The direction of the thrust in this case is downward.

In Sangamo mercury meters the thrust of the moving system is upward, amounting to three or four grams. In the Type D-5 watthour meter the lower bearing consists of a steel pivot on the armature shaft operating in a ring jewel guide set in the bottom of the mercury chamber. In all Type N Sangamo meters the lower bearing is reversed from this, consisting of a ring jewel of small diameter set in the bottom of the hub carrying the armature and operating on a flexible

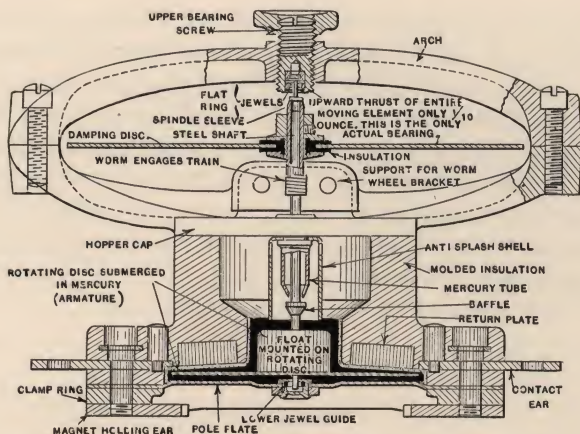


Fig. 32 Cross-section of mercury-motor element of Sangamo Type D-5 watt-hour meter showing bearing system.

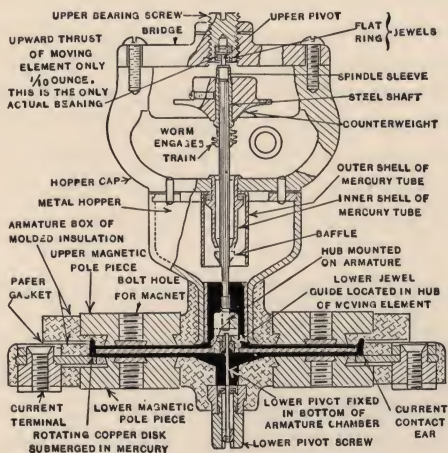


Fig. 33 Cross-section of mercury-motor element of Sangamo Type N ampere-hour meter showing bearing system.

steel pivot carried in the bottom wall of the mercury chamber. In all Type N meters for battery service, and in D-5 meters, the upper bearing is similar to a standard watch bearing, consisting of a ring jewel and flat jewel; the former guiding the upper pivot and the latter receiving the slight upward thrust. In Type NH amperehour meters for house service, as made in England, the upper bearing, to obtain maximum sensitivity, consists of a cup jewel, with a small diameter pivot self-locating in the center of the cup.

TORQUE IN AMERICAN METERS IS HIGH

THE full-load torque in modern meters varies from a minimum of 20 millimeter-grams in some of the cheaper types of foreign induction meters, to 150 millimeter-grams in several types of commutator meters. The torque in American induction meters varies from 40 to 50 millimeter-grams. In some foreign meters, having a heavy moving system, the torque is as high as 80 millimeter-grams. In commutator meters the torque is from 100 to 150 millimeter-grams, and in mercury-motor meters from 30 to 35 millimeter-grams for amperehour meters, and up to 75 millimeter-grams for watthour meters.

VOLTAGE-CIRCUIT CURRENT AND LOSSES

THE voltage-circuit loss or constant loss in direct-current watthour meters in standard American practice is from four to five watts in a 110-volt meter and in proportion for higher voltages. Some foreign commutator meters are made in which the voltage-circuit loss at 110 volts is about two watts, but this is done at the expense of other important features and

is not approved practice in this country. In induction meters the loss at 110-volts, 60 cycles varies from 0.75 watt to 1.75 watts, and even at frequencies as low as 25 cycles, from 1.2 watts to 2.0 watts. There is a wide difference of practice in induction meters as to the voltage and current relations in the voltage-coil circuit; that is in the power-factor of this circuit. The current in the voltage coils of different meters having practically the same constant loss, about 1.25 watts, varies from 0.035 ampere to 0.10 ampere. The question of voltage-circuit *current* as well as voltage-circuit *loss* is an important one where a large number of meters is involved.

METHODS OF DRIVING RECORDING TRAINS

THE speed of the moving system in different meters varies from a minimum of 20 r.p.m. up to 60 r.p.m. for induction meters, and as high as 180 r.p.m. in certain types of foreign commutator amperehour meters. Revolution counting in these meters is effected by a hand on a reduction gear from the moving system. In modern meters two methods of driving the recording trains or registers from the moving system are used. One method is by means of a worm on the main shaft of the meter communicating through a worm wheel to the gear train. Where a greater reduction is desired a compound attachment consisting of a second worm and worm wheel is used. The other method is by means of a pinion on the meter shaft driving a wheel on a vertical shaft, which in turn carries a worm as an integral part of the recording train. In the latter type of drive considerable trouble was formerly experienced with the lower bearing of the

vertical worm shaft but this trouble has been overcome in later years by special provision against wear of this bearing.

DIFFERENT TYPES OF METER TRAINS

THE friction in a meter train is a very important matter and of course should be very low as compared with the meter torque. In modern induction meters friction is usually so low that the accuracy of the meter at five per cent of rated load is not impaired more than one-half of one per cent by applying the recording train.

A type of train not used in the United States, but found on many foreign meters, is the cyclometer or direct-reading type. Various mechanisms have been developed for these trains, especially those of the so-called "quick acting type". The best mechanism is that of the English manufacturers, Ferranti, Limited, on which patents long since expired, and which is now used in more or less modified form by several other manufacturers. This is an ingenious and quite satisfactory type of cyclometer, but the best cyclometer train is a more frequent source of trouble

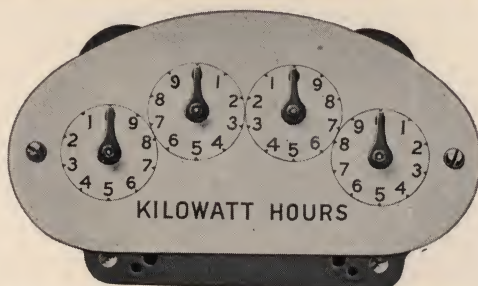


Fig. 34 Sangamo watt-hour meter register, standard pointer type.



Fig. 35 Sangamo cyclometer register.

than the ordinary clock train used on American meters. It has therefore been felt in this country that the

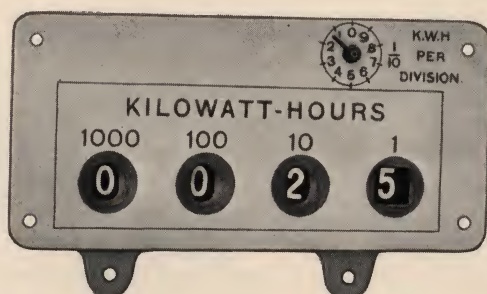


Fig. 36 Cyclometer register supplied on Ferranti meters.

advantage of ease of reading of the cyclometer train is outweighed by its greater cost and possible troubles.

METER ADJUSTMENTS

IN direct-current meters there are usually two adjustments only, that is for full-load and light-load accuracy. Light-load adjustment in direct-current meters has already been described, being obtained by moving a coil in the voltage circuit with respect to



Fig. 37 General Electric light-load adjustment.

the armature. Full-load adjustment in both direct-current and alternating-current meters is obtained either by shifting the permanent magnets with respect to the damping disk, or by shunting the flux of one or both magnets. The latter method has been successfully employed during the past twenty years in many types of meters.

Light-load adjustment in induction meters is obtained by distorting the shunt field. This is done either by means of a short-circuited conductor suitably located in the field with respect to the rotor, or by means of a small steel vane in suitable relation to the field. The light-load adjustment in some meters is arranged with micrometer screw so that it can be uniformly and accurately manipulated to obtain close accuracy of calibration.

A third adjustment, used only in induction meters, is for bringing the magnetic flux of the shunt magnet acting upon the disk, in exact quarter-phase relation with the electromotive force impressed on the coil.

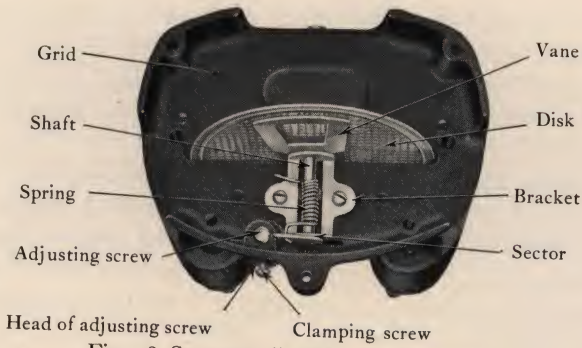


Fig. 38 Sangamo light-load adjustment.

This adjustment usually is referred to as phase-compensation or inductive-load adjustment. In some meters the device used for this purpose takes the form of a short-circuited copper or brass band movable vertically on the tip of the shunt magnet. By moving the band the number of leakage lines embraced by it can



Fig. 39 Power-factor compensation—Sangamo method.

be varied and thus the length of the secondary component of the field can be changed to give the desired 90-degree relation. In other meters the band is fixed and its effect is varied by means of a resistance-metal clamp or screw embraced in its circuit.

A third arrangement consists of a winding of several turns of wire on the tip of the shunt magnet short-circuited or closed through a fixed length of resistance wire. This method of compensation is less pleasing in mechanical appearance, but is perhaps the most dependable of those described.

PERMANENT MAGNETS OF GREAT IMPORTANCE

NO feature of the integrating meter is of more importance than the permanent magnets. If everything else were perfect and the magnets poor, the meter would be worthless. For this reason probably no other feature of meter construction has been given more thought and attention. Steel manufacturers have brought their best efforts to bear upon the production of a high-grade and uniform magnet steel and meter manufacturers take great pains to form, heat-treat, magnetize, age, and test their magnets properly. The need for these precautions can be readily appreciated by recalling the fact that the damping effect of the magnets varies with the square of their strength. A change of only one per cent therefore in the strength of the permanent magnets means a change of about two per cent in the speed of a meter. For this reason, every effort must be made to produce magnets which will retain their original strength unaltered for years. In the early days all meter magnets were of tungsten steel alloy, running from four to six per cent of tungsten. During the war tungsten became

so scarce and high in price that the great steel makers developed chromium magnet steel to take its place. While at first considerable trouble was experienced with this new steel, satisfactory and uniformly good magnets are now made of it. For a given type of magnet, tungsten steel will produce a slightly higher strength with equal permanence, but not enough to supplant the general use of chromium steel except for very special purposes.

METHODS OF "AGING" PERMANENT MAGNETS

FOR many years magnets were artificially "aged" by various processes of heating and vibration. At the present time the best aging process seems to be the plan of demagnetizing by alternating flux from an initial saturation value to a certain lower value which bears a definite relation to the saturation value.

The principle involved in this process is illustrated

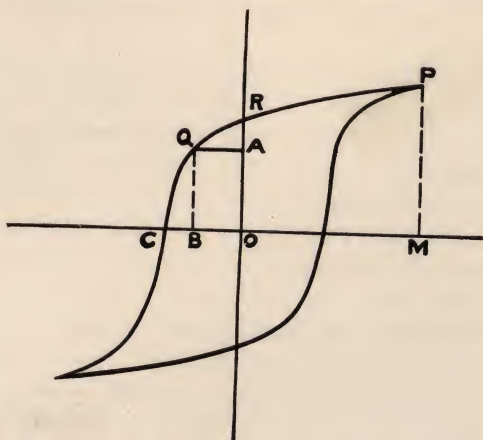


Fig. 40 Diagram illustrating the Sangamo method of aging magnets.

by Fig. 40. If OM represents the initial magnetizing force and MP the resultant magnetization for a given magnet, then OR may be considered as representing the magnetization after the removal of the magnetizing force. The magnetic part of the aging process consists in applying a demagnetizing force OB which reduces the magnetization further to OA. The magnet in this state will resist external or stray fields, the maximum value of which does not exceed OB. The value of OB is chosen so that it is considerably in excess of any stray field that may be met with in regular service.

This process of aging is now conscientiously carried out by several manufacturers and it can safely be said that today there need be little fear of magnets showing appreciable weakening in modern types of high grade meters.

PROGRESS IN METER LUBRICATION

THE problem of suitable oil for meter jewels is a most important one. Great progress has been made during the past two years in obtaining an acid-free, mineral-base oil for meter jewels in place of the refined fish oils which were in general use for many years. Fish oils were fairly satisfactory, but under certain conditions showed a tendency to become acid. The result was serious deterioration of pivots and consequent inaccuracies of meters on light load. Some meter engineers followed the practice of operating jewel bearings dry, but this practice is now generally condemned. With the availability of the mineral oils there is little doubt that the practice of oiling jewels will be generally followed.

Years ago, meter registers also were frequently oiled but a great deal of trouble was caused through the collection of grit and dirt on pivots of the train staffs. This was especially true with brass staffs running in brass plates. The practice was therefore discontinued except in special cases where steel pivots operating in brass plates or jewel bearings are used.

CHAPTER FOUR

Some Special Metering Problems

POLYPHASE-METERING PROBLEMS

POLYPHASE induction meters, as ordinarily employed, consist essentially of two single-phase elements having a single moving system with certain special arrangements for balancing or equalizing the torque of the two elements. The common polyphase meter is therefore equally suitable for use on three or four-wire, two-phase and on three-wire, three-phase systems, and will give a correct registration with either balanced or unbalanced loads.

A special problem arises in the case of three-phase four-wire systems. With balanced voltages a modified



Fig. 41 Sangamo vertical-type polyphase meter.



Fig. 42 Sangamo vertical-type polyphase meter with main and terminal-box covers removed.

form of two-element polyphase meter having a third current winding divided between the series elements of the meter will record accurately even when the currents are unbalanced. But this type of meter will not take care of unbalanced voltages between phases. To meet this condition, either three single-phase meters or a special type of polyphase meter must be employed. This special type of meter has three complete driving elements—one for each of the three phases. It also has three voltage elements, each connected from the neutral to one of the three phases. This type of meter was not used to any considerable extent in the United States until about two years ago, but it is now having an increasing application with the growth of four-wire, three-phase distribution systems. It is now furnished in standard service form as well as the switchboard type shown in Fig. 43, and may be equipped with a demand attachment in the register,

where it is desired to obtain the combined demand on a three-phase, four-wire system, for which purpose the use of three single-phase meters is unsatisfactory.

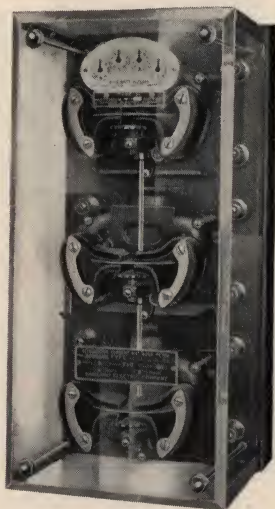


Fig. 43 Sangamo 4-wire, 3-phase, 3-disk meter.

THE HORIZONTAL POLYPHASE METER

ANOTHER type of polyphase meter having some very interesting characteristics and which has been recently brought out in the United States, Canada and several foreign countries, is the horizontal polyphase meter. It consists of two standard single-phase meter elements placed side by side and connected through differential gearing to a single register. On balanced load, the relative rate of rotation of the two elements gives immediate indication of the power-factor. Another advantage of this meter is the fact

that if either potential element goes bad the trouble is located at the time of inspection by the fact that one of the disks will not move under load.



Fig. 44 Sangamo horizontal-type polyphase meter.

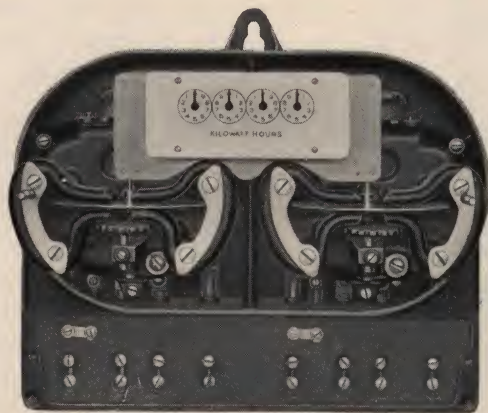


Fig. 45 Sangamo horizontal-type polyphase meter with main and terminal-box covers removed.

IMPORTANCE OF DEMAND METERING

THE general question of demand metering has become of greatly increased importance during the past few years, largely due to change in policy of the large power companies with respect to rates for the larger consumers of electric energy. Fundamentally, electricity should be sold on the basis of two factors; first, the customer's demand with respect to his connected load, and second, his actual consumption of energy, expressed in kilowatt-hours. The time of occurrence of the demand with respect to the station peak, the duration of the demand, and other details vary with different users and frequently with other factors. But fundamentally there is absolute need today for demand devices to give the information necessary to establish and apply rates in accordance with a customer's demand. For very small residence consumers a straight energy charge is probably the only practicable rate system at this time. But for larger commercial consumers and for all power customers some type of demand device should be used.

DIFFERENT TYPES OF DEMAND METERS

THE earliest demand meter of importance was the Wright thermal demand meter. In this meter liquid within a "U"-shaped tube was forced over one end of the "U" into a graduated tube by expanding air heated by a coil connected to a shunt in the load circuit. After a certain definite period of time, the rate at which heat was dissipated by the confined air was equal to the rate at which it was being heated and the flow of liquid into the calibrated tube ceased. The demand was then indicated by the height of the

liquid column in the calibrated tube. This type of demand meter was successfully used for a number of years but has now been superseded by either the "block interval" type of demand device or by the Lincoln thermal demand meter. The Lincoln demand meter, in indicating and in graphic form, has met with much favorable reception in Canada during the past several years. The Lincoln meter is based on fundamental relation between a customer's load and its heating effect upon the generating and distribution system. In other words, the meter indication follows a logarithmic law with respect to the heating effect of the load passed through the instrument instead of operating on a definite or block-time interval principle as in the case of instruments based on the Merz patents, recently expired.

The demand attachments now supplied on the principal makes of alternating-current watthour meters, in which an auxiliary hand gives an indication of the maximum demand in kilowatts, are based on this

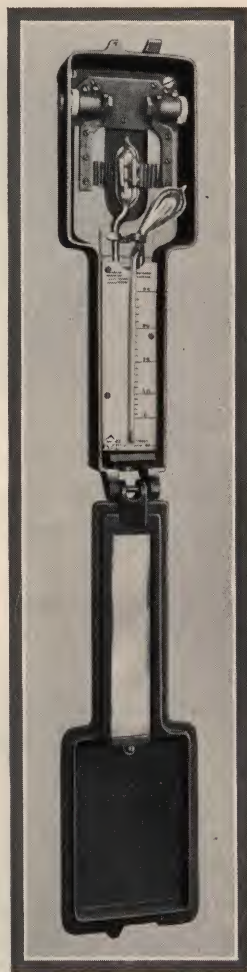


Fig. 46 Wright demand meter with cover opened.



Fig. 47 Lincoln polyphase maximum-demand meter.

principle. The time interval is usually obtained by means of a small induction-reaction or induction

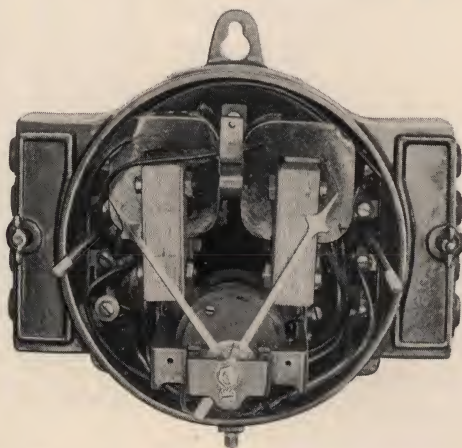


Fig. 48 Lincoln polyphase maximum-demand meter with cover and dial removed.

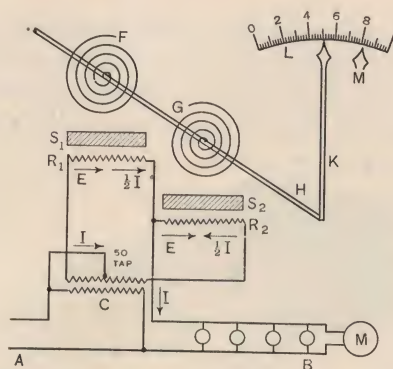


Fig. 49 Coil scheme and wiring of Lincoln maximum-demand meter.

motor incorporated in the meter register. On direct-current watthour meters similar demand devices are used but the time interval must be obtained by a suitable clock.

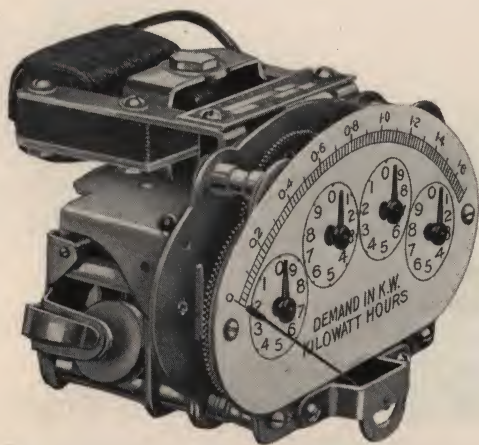


Fig. 50 Sangamo maximum-demand register.

Demand intervals of 15 and 30 minutes are most common. But with very large, rapidly varying loads on hydro-electric systems, demand intervals as low as one, three or five minutes are employed. For this

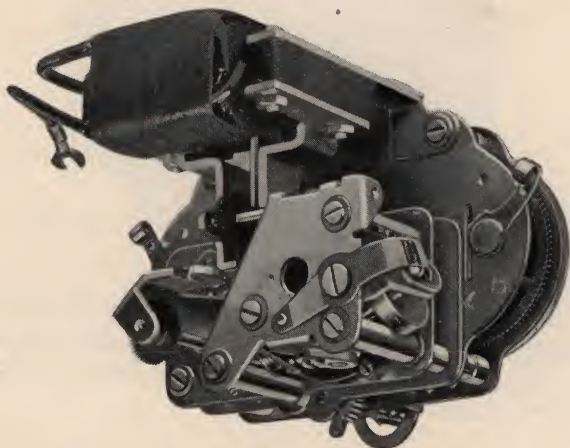


Fig. 51 Rear view of Sangamo maximum-demand register.

service, special types of demand devices, usually in the form of mechanisms operated from contacts in the watthour meter, are used. This principle is also used for the longer time intervals in the case of recording or printing demand meters used on very large and important loads.

THE NEED FOR KILOVOLT-AMPERE DEMAND METERS

THE most recent work in demand-meter design has been in response to an increasing need during the past few years for a meter that would give a rec-

ord of kilovolt-amperes as well as kilowatts, on important power loads. If these records are simultaneous, they would also give the power-factor for the load for each time interval. Several solutions of this problem have been proposed, but the most practical is undoubtedly the combination of two polyphase watt-hour meters; one connected as usual, to measure energy, and the other connected in such a manner, either by external transformation or special construction of potential circuits, to obtain quadrature relation in the potential elements with respect to the potential elements of the watt-hour meter, and thus measure the reactive component.

This fundamental principle is used in the Ennis Device, developed by the Westinghouse Electric & Manufacturing Company. The device makes use of a ball which is driven by two disks and which in turn drives

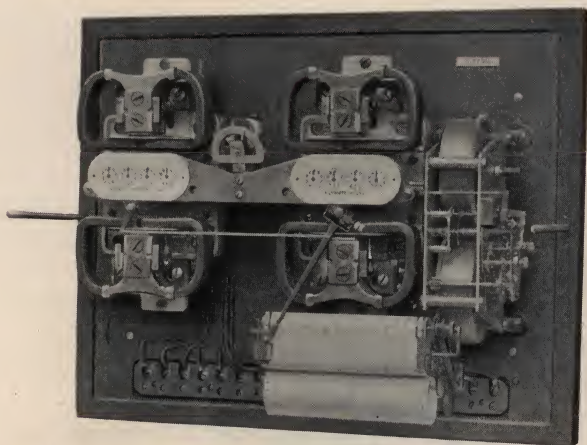


Fig. 52 Westinghouse "Universal" Meter for measuring volt-amperes, etc. (Ennis principle).

a third disk. The angular motion of the third disk is the vector sum of the motions of the two driving disks. Of the latter, one is driven by the energy component meter and the other by the reactive component meter. The third disk is mounted on a movable frame so that it rolls on a great circle of the sphere, the position being determined by the respective speed of the disks driven by the reactive and energy component meters. This indicates the power-factor as well as showing on a graphic chart the kilovolt-ampere demand over a predetermined time interval.

A very different arrangement, although embodying the fundamental principle of measurement of the two components by means of two meters, has been developed by the Sangamo Electric Company. From the energy meter, through suitable contact means and a simple arrangement of motor in the recording device,

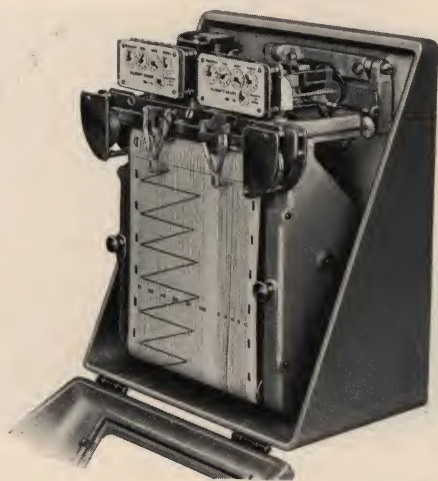


Fig. 53 Sangamo kilovolt-ampere demand meter.

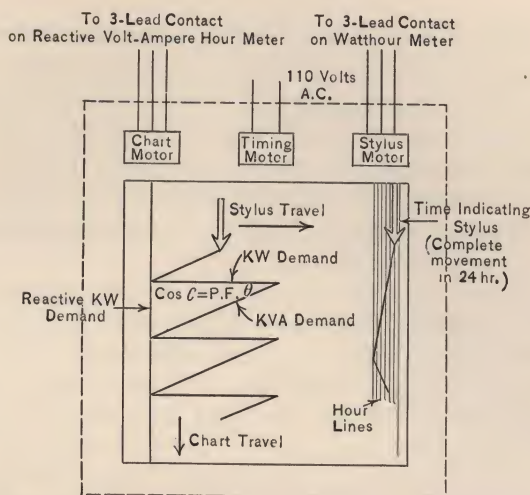


Fig. 54 Schematic diagram showing principle of Sangamo kilovolt-ampere demand meter.

a stylus is caused to move at right angles to the travel of a paper chart, the motion of the chart being obtained through another motor operated by contacts in the reactive-component meter. The stylus thus draws a diagonal line on the chart, the angle of which with respect to either the horizontal or vertical sides of each successive triangle, gives the power-factor for each demand interval, while the horizontal or base line gives kilowatt demand, and the diagonal line or hypotenuse of the triangle, gives kilovolt-ampere demand. By a simple timing device operated from a synchronous motor or other suitable means, the pen is reset to zero at the end of each time interval. On the chart a separate section with another pen operated back and forth every twenty-four hours, gives the time of occurrence of each demand by simple inspection.

tion of the chart. This type of meter makes it possible to obtain in a single instrument, a reproduction on the two dials, of the kilowatt-hour and reactive component-hour readings of the actuating meters, also the kilowatt demand, the kilovolt-ampere, demand the reactive-component demand, the power-factor for each demand period, and the time of occurrence of each period measured.

The measurement of demand in kilowatts and in kilovolt-amperes is a phase of the metering problem which promises to be of great importance. With the enormous increase in the size of power loads, it is becoming vitally important that the central station know the power-factor of a customer's demand requirements. With this knowledge the central station will be in a better position to recognize power-factor in its rate scheme and to better the power-factors of its loads through the application of penalties for low power-factor or bonuses for high power-factor.

CHAPTER FIVE

Importance of Instrument-Transformer Accuracy

A MATTER of very great importance in metering which has not been given the consideration it deserves until recently, is the accuracy of instrument transformers. This is particularly true of the current transformer, in which accuracy cannot be as easily obtained as in the voltage transformer. The current transformer, despite its apparent simplicity, is one of the most complex and difficult devices. The importance of keeping the phase angle down to the lowest possible point in current transformers, especially where used with polyphase meters, can readily be appreciated from the following fact; a deviation of 20 minutes in phase angle from the theoretical 180 degrees between the primary and secondary currents causes an error of one per cent in meter registration

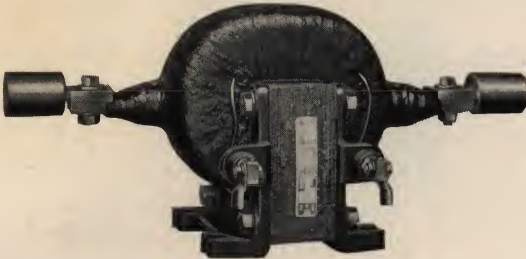


Fig. 55 Sangamo Type F current transformer.

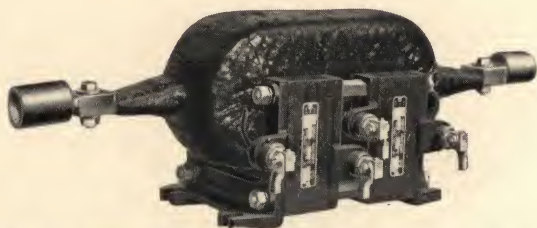


Fig. 56 Sangamo Type F-2S current transformer with two separate secondary circuits, one for meters and the other for auxiliary devices.

at fifty per cent power-factor. The matter of ratio is also of importance. But this error in the combination of meter and transformer is always in direct proportion to the error in transformer ratio and is usually not nearly so great as possible errors arising from phase displacement.

Current transformers of several makes are now available in which the phase angle is from a few minutes negative at full load to a few minutes positive at ten per cent load and with a ratio deviation throughout this range of less than one-quarter of one per cent. A degree of accuracy almost equal to that obtainable with a polyphase meter alone can hence be obtained with such transformers.

THE BROOKS TWO-STAGE CURRENT TRANSFORMERS

A CURRENT transformer of particular interest is the two-stage transformer invented by Mr. H. B. Brooks of the Bureau of Standards. This transformer is exceedingly well adapted for service where a single-turn primary is used at comparatively low current values. A full load of 200 amperes through a single primary turn of this transformer is sufficient to



Fig. 57 Sangamo Type BK Brooks-type two-stage current transformer.



Fig. 58 Sangamo Type BHV Brooks-type two-stage current transformer for mounting over high-voltage bushings.

give an extraordinary degree of accuracy in the ratio and phase angle of the secondary current over a wide range of load. The principal secondary of the Brooks transformer is connected to the usual series coils in the watthour meter while the auxiliary secondary of the transformer is connected to an auxiliary set of coils on the series magnet of the meter. The combined energizing effects of the main and auxiliary coils wound upon the series magnet of the meter is such as to give results which would otherwise be impossible with such a low number of primary ampere-turns.

CHAPTER SIX

Special Types of Meters

THERE are many special types of meters to which only brief reference can be made. Among them is the two-rate meter which is used in many foreign countries to encourage the use of current for heating and cooking purposes at off-peak periods.



Fig. 59 German type two-rate meter.

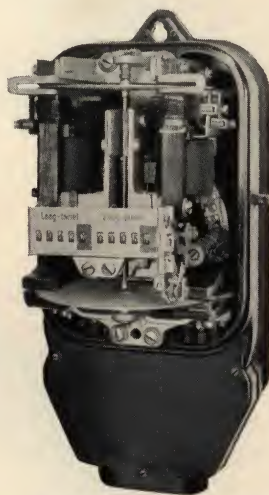


Fig. 60 German type two-rate meter with cover removed.

This type of meter has two registers geared at different rates. One register is driven by the meter through a certain part of the day while the other register is automatically substituted at the time of day when it is desired to give a different rate.

Another type of meter that deserves mention is the

prepayment electric meter. Unlike the prepayment gas meter, it has never found much favor in this country, largely because of its complicated construction and high cost. This type of meter seems to be gradually dying out, and it is unfortunate that so much time and expense was at one time put upon its development.

An important special type of meter is the direct-current shunted meter with distant dial. One of these meters has been in use at the Hydraulic Power Company, Niagara Falls, for a number of years on a circuit transmitting 60,000 horsepower. The dial, which is operated from contacts in the meter proper, is located at a long distance from the meter.

INTERESTING METER APPLICATIONS

THERE are many interesting applications of meters outside of the measurement of direct and alternating-current energy for light and power to consumers. For example, a special type of direct-current mercury-motor meter is now used on electric-railway cars in many of the principal cities through the world to serve as a check on the consumption of energy for the propulsion of the car. Their use induces motormen to effect economies in the use of energy. At the same time the meters enable faults in equipment to be detected and enable inspection of equipment to be made on the basis of units of energy consumed. In many cases the savings resulting from the use of these meters repay the entire cost of installation several times in a single year.

Direct-current amperehour meters have also been generally employed in connection with storage batteries for a number of years. These meters are ar-

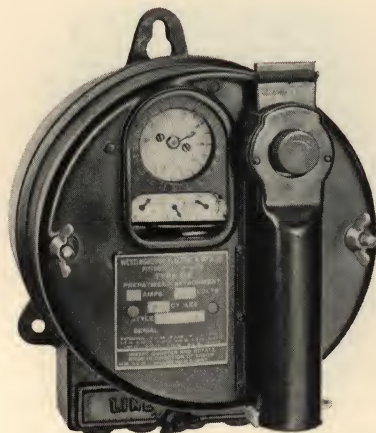


Fig. 61 Westinghouse prepayment meter.

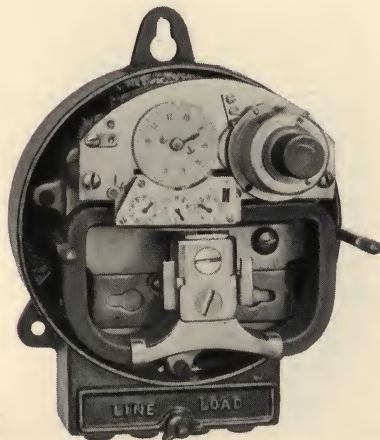


Fig. 62 Westinghouse prepayment meter with cover removed.

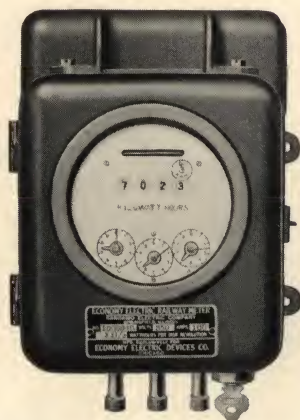


Fig. 63 Sangamo railway economy meter.

ranged with special gear trains and dials to show both charge and discharge. Many are also equipped with one or more special features as follows: to give slower speed on charge than discharge to compensate for inefficiency of batteries, or to trip a circuit-breaker at termination of charge. Amperehour meters are now used to control automatically the charging of batteries in train-lighting equipment on nearly all electric-lighted railroad cars in this and other countries. They are also widely employed for the control of large plating and important electrolytic processes.

GREAT HELP RENDERED BY METER COMMITTEES

THERE are other special applications of electric meters of considerable interest but they are too numerous to mention. No discussion of meter history and progress would be complete, however, without paying a tribute, as a manufacturer, to the splendid effect which the two national meter committees have

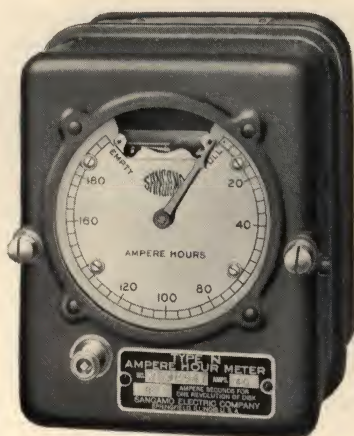


Fig. 64 Sangamo Type NF amperehour meter.

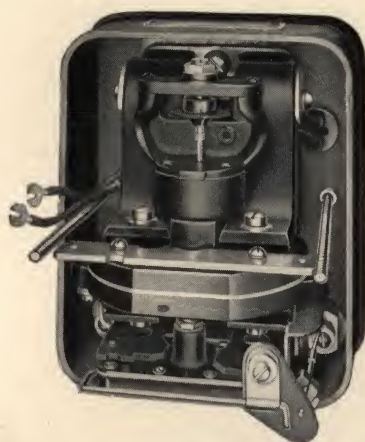


Fig. 65 Sangamo Type NF amperehour meter with cover removed.

had on the meter art. These committees of the Edison Association of Illuminating Companies and of the National Electric Light Association were organized over twenty-five years ago and have brought about an intimate relationship between meter manufacturers and many of the leading central-station men of the country. These committees, through their presentation of problems and their advice on disputed matters of design, have done more to promote the art and bring about the present highly standardized and perfected type of meters than has any other influence.

Some idea of the real engineering effort that has been expended in the electric meter art during the forty years of its existence has been given in the foregoing pages. Without the accurate meter of today—accurate initially and in service as well—the central stations of this country would be unable to go ahead with any prospect of continued successful earnings, and thus of continued ability to serve the public.

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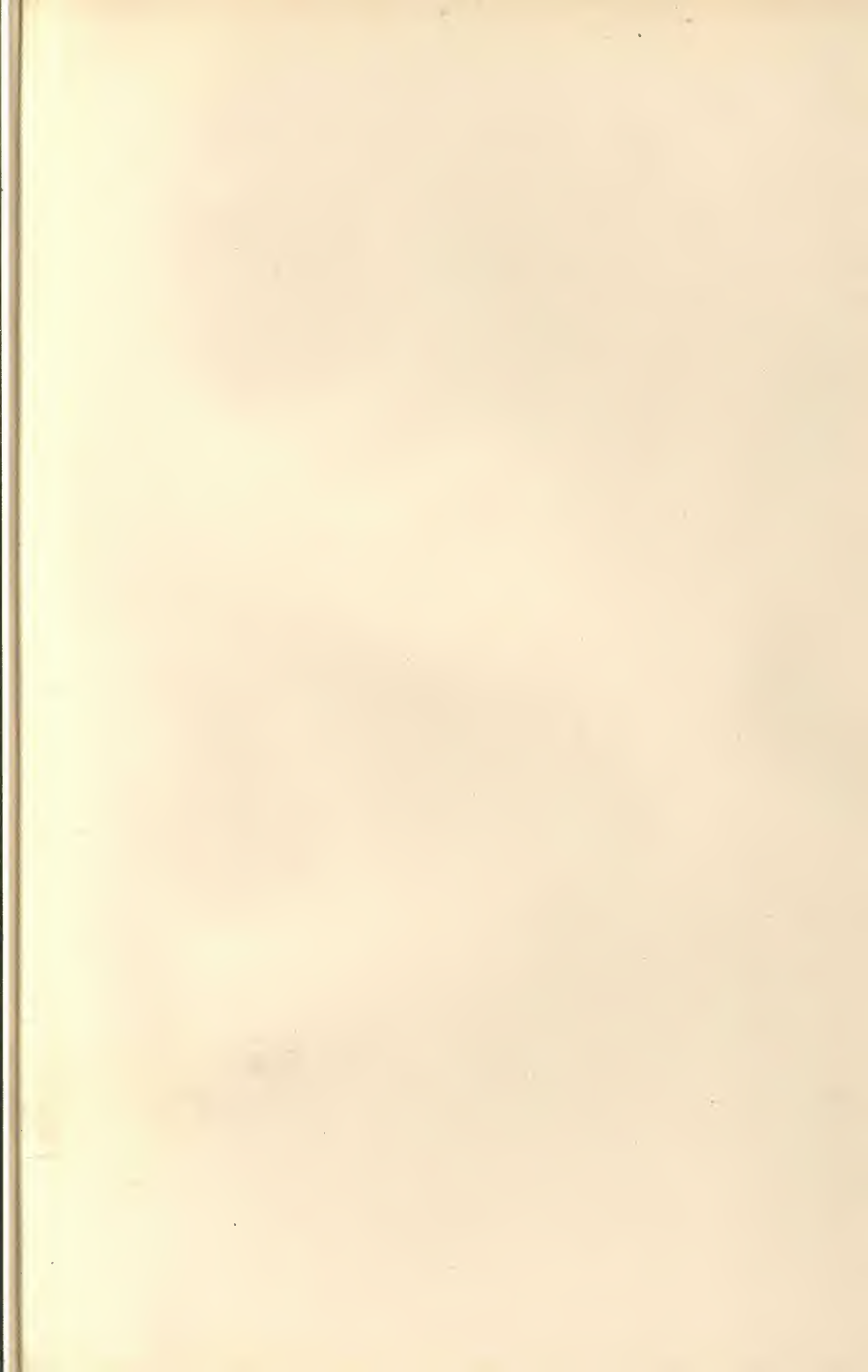


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